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XXXI. *Experiments on the Power that Animals, when placed in certain Circumstances, possess of producing Cold.* By Adair Crawford, M. D.; communicated by Sir Joseph Banks, Bart. P. R. S.

Read June 14, 1781.

IN the following paper I shall lay before the Society the result of some experiments, which I made in the course of the last summer, on the power that animals, when placed in certain circumstances, possess, of producing cold, having premised a few remarks on the progressive improvements which have been made in the knowledge of heat in general.

The opinions of the ancients, respecting the nature and properties of fire, consisted of bold conjectures, which seem rather to have been the offspring of a lively and vigorous imagination, than of a just and correct judgement: their ideas on this subject being evidently derived, not so much from an accurate observation of facts, as from those sentiments of admiration and awe which many of the phenomena of fire are calculated to excite. Thus, this element was supposed, on the original formation of the universe, to have ascended to the highest place, and to have occupied the region of the heavens: it was conceived to be the principle which first communicated life and activity to the animal kingdom: it was considered as constituting the essence of inferior intellectual beings; and, by many of the ancient nations, it was revered as the supreme Deity. Indeed the profound veneration with which the element of

fire was contemplated, for a long succession of ages, by a great part of mankind, appears to be one of the most curious circumstances in the history of antient opinions. To account for this we may observe, that there is no principle in nature, obvious to the senses, which produces such important effects in the material system, and which, at the same time, in the mode of its operation, is so obscure and incomprehensible.

It appears to be accumulated in an immense quantity in the sun and fixed stars, from whence its beneficial influence seems to be continually diffused over the universe: it is the great instrument by means of which the changes of the seasons are effected; the diversity of climates is chiefly owing to the various proportions in which it is distributed throughout the earth. If we add to this the mighty alterations which have been produced in human affairs by the introduction of artificial fire, by its employment in the separation of metals from their ores, and in the various arts which are subservient to the comfort, the ornament, and the preservation, of the species, it will not appear surprizing, that in a rude and ignorant age, this wonderful principle should have been considered as endued with life and intelligence, and that it should have become the object of religious veneration.

In the dark ages the alchymists regarded pure fire as the residence of the Deity: they conceived it to be uncreated and immense, and attributed to its influence most of the phenomena of nature. Indeed, it is not wonderful that they should have assigned it a high rank in the scale of being, as it was the great agent which they employed in the chymical analysis of bodies, and was the instrument of those discoveries that attracted such universal admiration, and that enabled them so successfully to impose upon the ignorance and credulity of the times.

Upon

Upon the revival of literature, the importance of this branch of science began very soon to engage the attention of philosophers. It could not escape the general observation, in a penetrating and inquisitive age, when the powers of the human mind were employed with so much ardour and success in exploring the operations of nature, that the element of fire acts a principal part in the system of the world; that by the influence of this element those motions are begun and supported in the animal and vegetable kingdoms, which are essential to the production and preservation of life; and that it is the great agent in those successive combinations and decompositions, by which all things on the surface of the earth, and probably throughout the universe, are kept in a continual fluctuation.

But though the utility of this branch of science was perceived, yet the progress that was made in the cultivation of it did not keep pace with the opinion which men entertained of its importance. Our senses inform us, that heat has a real existence, but they give us no direct information with regard to its nature and properties: it is endowed with such infinite subtilty, that it has been called, by a very eminent philosopher, an occult quality: by some it has even been considered as an immaterial being. It is, therefore, with great difficulty that it can be made the subject of philosophical investigation; and hence the opinions of men concerning it have been fluctuating and various, and the words which express it vague and ambiguous.

The first step that was taken with a view to the cultivation of this branch of science was the construction of a machine for measuring the variations of sensible heat; observing, that heat has the power of expanding bodies, and considering

the degree of expansion as proportional to the increase of heat, philosophers have endeavoured by means of the former to render the latter obvious to the senses.

To this important invention, the author of which cannot be distinctly traced, we are indebted for all the succeeding improvements in the philosophy of heat. By means of it men were enabled to establish a variety of interesting facts, and to bring some of the most obscure and intricate phenomena of nature to the test of experiment. The opinion, that the heats inherent in various heterogeneous substances differed from each other in kind, as well as in degree, was now exploded, since all were found to produce similar effects upon the thermometer. The increase and diminution of temperature in the different seasons and climates, the laws which nature observes in the heating and cooling of bodies, the melting, the vaporific, and thinning points, and the degrees of heat in the animal, the mineral, and the vegetable kingdoms, were accurately determined. In consequence of the attention that was paid to this subject, many curious questions arose, which have long exercised the ingenuity of philosophers. That property of heat by which it is capable of expanding the densest and hardest bodies; its power in producing fluidity; its tendency to an equilibrium; and the causes of its various distribution throughout the different substances in nature, have become the objects of philosophical enquiry. It was observed, that some bodies on exposure to heat, become red and luminous, but are incapable of producing flame, or of maintaining fire: that, on the contrary, others, by the application of fire, and the contact of fresh air, kindle into flame, and continue to emit light and heat, apparently from a source within themselves, till they are consumed. Hence arose the questions concerning the pabulum

lum of fire, the use of the air in inflammation, and the distinction of bodies into combustible and incombustible.

From the first dawnings of philosophy it must have been perceived, that most animals have a higher temperature than the medium in which they live; and that a constant succession of fresh air is necessary to the support of animal life. The causes of these phenomena have afforded matter for much speculation in ancient as well as modern times: but the discovery that animals have, in certain circumstances, the power of keeping themselves at a lower temperature than the surrounding medium, was reserved for the industry of the present age.

This discovery seems originally to have arisen from observations on the heat of the human body in warm climates. It was mentioned by Governor ELLIS in 1758; it was taught by Dr. CULLEN before the year 1765; and at length it was completely established by the experiments of Dr. FORDYCE in heated rooms, which were laid before the Society in 1774.

In the course of these experiments the doctor remained in a moist air heated to  $130^{\circ}$  for the space of fifteen minutes, during which time the thermometer under his tongue stood at  $100^{\circ}$ , his pulse made 139 beats in a minute, his respiration was but little affected, and streams of water ran down over his whole body, proceeding from the condensation of vapour, as evidently appeared from a similar condensation on the side of a Florentine flask that had been filled with water at  $100^{\circ}$ .

He found, however, that he could bear a much greater degree of heat when the air was dry. In this situation, he frequently supported, naked, for a considerable time, without much inconvenience, the heat of  $260^{\circ}$ , his body preserving very nearly its proper temperature, being never raised more than  $2^{\circ}$  above the natural standard.

Various opinions have been entertained with regard to the causes of the facts which were established by these experiments. Some have attributed the cold solely to evaporation, and have conceived that the same degree of refrigeration would have been produced by an equal mass of dead matter, containing an equal quantity of moisture. Others have affirmed, that the cold did not arise solely from this cause; but have maintained, that it depended partly upon the energy of the vital principle, being greater than what would have been produced by an equal mass of inanimate matter.

The ingenious Dr. MUNRO, of Edinburgh, ascribes the cold in the above mentioned experiments to the circulation of the blood, in consequence of which the warmer fluids are continually propelled from the surface towards the center, where they are mixed with blood at a lower temperature, and hence the animal is slowly heated, in the same manner as the water in a deep lake, during the winter, is slowly cooled, and not without a long continuance of frost congealed, no part of it becoming solid till the whole is brought down to the freezing point.

The following experiments were made with a view to determine with greater certainty the causes of the refrigeration in the above instances.

To discover whether the cold produced by a living animal, placed in air hotter than its body, be not greater than what would be produced by an equal mass of inanimate matter, I took a living and a dead frog, equally moist, and of nearly the same bulk, the former of which was at  $67^{\circ}$ , the latter at  $68^{\circ}$ , and laid them upon flannel in air which had been raised to  $106^{\circ}$ . In the course of twenty-five minutes the order of heating was as follows\*.

\* In the two following experiments the thermometers were placed in contact with the skin of the animals under the axillæ.

		Air.	Dead frog.	Living frog.
In	1	—	70 $\frac{1}{2}$	67 $\frac{1}{2}$
	2	102	72	68
	3	100	72 $\frac{1}{2}$	69 $\frac{1}{2}$
	4	100	73	70
	25	95	81 $\frac{1}{4}$	78 $\frac{1}{4}$

The thermometer being introduced into the stomach, the internal heat of the animals was found to be the same with that at the surface.

From hence it appears, that the living frog acquired heat more slowly than the dead one. Its vital powers must, therefore, have been active in the generation of cold.

To determine whether the cold produced in this instance depended solely upon the evaporation from the surface, increased by the energy of the vital principle, a living and dead frog were taken at 75°, and were immersed in water at 93°, the living frog being placed in such a situation as not to interrupt respiration.

		Dead frog.	Living frog.
In	1	85	81
	2	88 $\frac{1}{2}$	85
	3	90 $\frac{1}{2}$	87
	5	91 $\frac{1}{2}$	89
	6	91 $\frac{1}{2}$	89
	8	91 $\frac{1}{2}$	89

These experiments prove, that living frogs have the faculty of resisting heat, or producing cold, when immersed in warm water: and the experiments of Dr. FORDYCE prove, that the human body has the same power in a moist as well as in a dry

\* In the above experiment the water, by the cold frogs and by the agitation which it suffered during their immersion, was reduced nearly to 91 $\frac{1}{2}$ °.

air;

air: it is therefore highly probable, that this power does not depend solely upon evaporation.

It may not be improper here to observe, that healthy frogs, in an atmosphere above  $70^{\circ}$ , keep themselves at a lower temperature than the external air, but are warmer internally than at the surface of their bodies: for when the air was  $77^{\circ}$ , a frog was found to be  $68^{\circ}$ , the thermometer being placed in contact with the skin; but when the thermometer was introduced into the stomach, it rose to  $70^{\circ}\frac{1}{2}$ .

It may likewise be proper to mention, that an animal of the same species placed in water at  $61^{\circ}$ , was found to be nearly  $61^{\circ}\frac{1}{4}$  at the surface, and internally it was  $66^{\circ}\frac{1}{2}$ . These observations are meant to extend only to frogs living in air or water at the common temperature of the atmosphere in summer. They do not hold with respect to those animals, when plunged suddenly into a warm medium, as in the preceding experiments.

To determine whether other animals also have the power of producing cold, when surrounded with water above the standard of their natural heat, a dog at  $102^{\circ}$  was immersed in water at  $114^{\circ}$ , the thermometer being closely applied to the skin under the axilla, and so much of his head being uncovered as to allow him a free respiration.

In 5 minutes the dog was  $108^{\circ}$ , water  $112^{\circ}$

6            -            -             $109$             -             $112$

11           -           -             $108$            -             $112$  the respiration

having become very rapid.

In thirteen minutes the dog was  $108^{\circ}$ , water  $112^{\circ}$ , the respiration being still more rapid.

In about half an hour the dog was  $109^{\circ}$ , water  $112^{\circ}$ , the animal was then in a very languid state.

Small

Small quantities of blood being drawn from the femoral artery, and from a contiguous vein, the temperature did not seem to be much increased above the natural standard, and the sensible heat of the former appeared to be nearly the same with that of the latter.

In this experiment a remarkable change was produced in the appearance of the venous blood: for it is well known, that in the natural state, the colour of the venous blood is a dark red, that of the arterial being light and florid; but after the animal, in the experiment in question, had been immersed in warm water for half an hour, the venous blood assumed very nearly the hue of the arterial, and resembled it so much in appearance, that it was difficult to distinguish between them. It is proper to observe, that the animal which was the subject of this experiment, had been previously weakened by losing a considerable quantity of blood a few days before. When the experiment was repeated with dogs which had not suffered a similar evacuation, the change in the colour of the venous blood was more gradual; but in every instance in which the trial was made, and it was repeated six times, the alteration was so remarkable, that the blood which was taken in the warm bath could readily be distinguished from that which had been taken from the same vein before immersion, by those who were unacquainted with the motives or circumstances of the experiment.

To discover whether a similar change would be produced in the colour of the venous blood in hot air, a dog at  $102^{\circ}$  was placed in air at  $134^{\circ}$ .

In ten minutes the temperature of the dog was  $104^{\circ}\frac{1}{2}$ , that of the air being  $130$ . In fifteen minutes the dog was  $106^{\circ}$ , the air  $130^{\circ}$ . A small quantity of blood was then taken from the

jugular vein, the colour of which was sensibly altered, being much lighter than in the natural state.

The effect which is produced by external heat upon the colour of the venous blood, seems to confirm the following opinion, which was first suggested by my worthy and ingenious friend Mr. WILSON, of Glasgow. Admitting that the sensible heat of animals depends upon the separation of absolute heat from the blood by means of its union with the phlogistic principle in the minute vessels, may there not be a certain temperature at which that fluid is no longer capable of combining with phlogiston, and at which it must of course cease to give off heat? It was partly with a view to investigate the truth of this opinion that I was led to make the experiments recited above.

I shall now endeavour, from the preceding facts, to explain what appear to me to be the true causes of the cold produced by animals when placed in a medium, the temperature of which is above the standard of their natural heat.

In a work which I some time ago laid before the public, having attempted to prove, that animal heat depends upon the separation of elementary fire from the air in the process of respiration, I observed, that when an animal is placed in a warm medium, if the evaporation from the lungs be increased to a certain degree, the whole of the heat separated from the air will be absorbed by the aqueous vapour.

From the experiments on venous and arterial blood, recited in the third section of that work, it appears, that the capacity of the blood for containing heat is so much augmented in the lungs, that, if its temperature were not supported by the heat which is separated from the air, in the process of respiration, it would sink  $30^{\circ}$ . Hence, if the evaporation from the lungs be so much increased as to carry off the whole of the heat that is detached

detached from the air, the arterial blood when it returns by the pulmonary vein will have its sensible heat greatly diminished, and will consequently absorb heat from the vessels which are in contact with it, and from the parts adjacent. The heat which is thus absorbed in the greater vessels will again be extricated in the capillaries, where the blood receives a fresh addition of phlogiston. If, in these circumstances, the blood during each revolution were to be equally impregnated with this latter principle, it is manifest, that the whole effect of the above process would be to cool the system at the center, and to heat it at the surface; or to convey the heat to that part of the body where it is capable of being instantly carried off by evaporation. But it appears, from the experiments which have been last recited, that, when an animal is placed in a heated medium, the sanguineous mass, during each revolution, is *less* impregnated with phlogiston; for we have seen, that the venous blood, in these circumstances, becomes gradually paler and paler in its colour till at length it acquires very nearly the appearance of the arterial: and it is rendered highly probable by the experiments of Dr. PRIESTLEY, that the dark and livid colour of the blood in the veins depends upon its combination with phlogiston in the minute vessels. Since, therefore, in a heated medium, this fluid does not assume the same livid hue, we may conclude, that it does not attract an equal quantity of the phlogistic principle\*.

\* It is of no consequence in the above argument, whether we suppose, with Dr. PRIESTLEY, that the alteration of colour in the blood depends upon its combination with phlogiston in the capillary arteries, or maintain with some other philosophers that this alteration arises from a change produced in the blood itself by the action of the vessels; it is sufficient for our purpose to assume it as a fact, which, I think, has been proved by direct experiment, that, in the natural state of the animal, the blood undergoes a change in the capillaries, by which its capacity for containing heat diminished; and that in a heated medium it does not undergo a similar change.

It follows, that the quantity of heat given off by the blood in the capillaries will not be equal to that which it had absorbed in the greater vessels, or positive cold will be produced. If the blood, for example, in its passage to the capillaries, absorb from the greater vessels a quantity of heat as  $30^{\circ}$ , and if in consequence of its receiving a less impregnation of phlogiston than formerly, it give off at the extreme vessels a quantity of heat only as  $20^{\circ}$ , it is manifest, that upon the whole a degree of refrigeration will be produced as  $10^{\circ}$ , and this cause of refrigeration will continue to act while the venous blood is gradually assuming the hue of the arterial, till the difference between them is obliterated; after which it will cease to operate. Thus it appears, that when animals are placed in a warm medium, the same process which formerly supplied them with heat becomes for a time the instrument of producing cold, and probably preserves them from such rapid alterations of temperature as might be fatal to life.

Upon the whole, the increased evaporation, the diminution of that power by which the blood in the natural state is impregnated with phlogiston, and the constant reflux of the heated fluids towards the internal parts, seem to be the great causes upon which the refrigeration depends. Having found that the attraction of the blood to phlogiston was diminished by heat, it appeared probable, on the other hand, that it would be increased by cold. To determine this, a dog at  $100^{\circ}$  was immersed in water nearly at  $45^{\circ}$ . In about a quarter of an hour a small quantity of blood was taken from the jugular vein, which was evidently much deeper in its colour than that which had been taken in the warm bath, and appeared to me, as well as to several other gentlemen, to be the darkest venous blood we had ever seen.

From this experiment, compared with those which have been recited above, we may perceive the reason why animals preserve an equal temperature, notwithstanding the great variations in the heat of the atmosphere, arising from the vicissitudes of the weather, and the difference of season and climate: for, as soon as by exposure to external cold, an unusual dissipation of the vital heat is produced, the blood, in the course of the circulation, begins to be more deeply impregnated with the phlogistic principle. It will therefore furnish a more copious supply of this principle to the air in the lungs, and will imbibe a greater quantity of fire in return.

In summer, on the contrary, the reverse of this will take place, less phlogiston will be attracted in the minute vessels, and less fire will be absorbed from the air.

And hence the power of generating heat is in all cases proportioned to the demand. It is increased by the winter colds, diminished by the summer heats: it is totally suspended or converted into a contrary power, according as the exigencies of the animal may require.

From the changes which are produced in the colour of the venous blood by heat and cold, we may likewise perceive the reason why the temperature of the body is frequently increased by plunging suddenly into cold water, and why the warm bath has such powerful effects in cooling the system, and in removing a general or partial tendency to inflammation.

